PB87-203287

Wind Transport of Scalars and Pollutants

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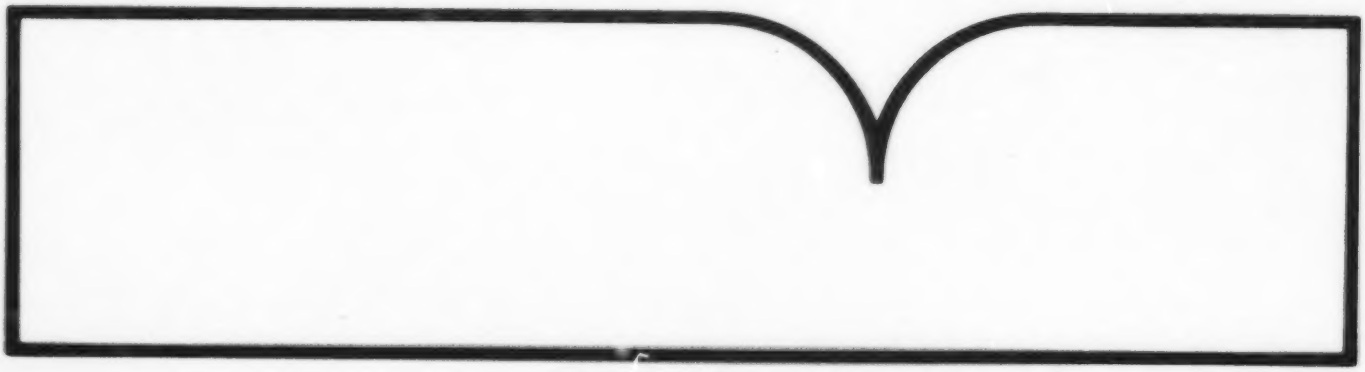
Research Triangle Park, NC

Jun 87



U.S. Department of Commerce
National Technical Information Service
NTIS

PB87-203287

EPA/600/D-87/200
June 1987

WIND TRANSPORT OF SCALARS AND POLLUTANTS

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TECHNICAL REPORT DATA
(Please read Instructions on the reverse before completing)

1. REPORT NO.	2.	3. RECIPIENT'S ACCESSION NO.
EPA/600/D-87/200		

4. TITLE AND SUBTITLE	5. REPORT DATE
WIND TRANSPORT OF SCALARS AND POLLUTANTS	June 1987
	6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S)	8. PERFORMING ORGANIZATION REPORT NO.
Roger S. Thompson, FMS, MD, ASRL, EPA, RPT, NC 27711.	
9. PERFORMING ORGANIZATION NAME AND ADDRESS	10. PROGRAM ELEMENT NO.
Atmospheric Sciences Research Laboratory Office of Research and Development U.S. Environmental Protection Agency Research Triangle Park, NC 27711	A101/B/68/08-6221(FY-87)
	11. CONTRACT/GRANT NO.
12. SPONSORING AGENCY NAME AND ADDRESS	13. TYPE OF REPORT AND PERIOD COVERED
Atmospheric Sciences Research Laboratory - RTP, NC Office of Research and Development U.S. Environmental Protection Agency Research Triangle Park, NC 27711	14. SPONSORING AGENCY CODE EPA/600/09

15. SUPPLEMENTARY NOTES

16. ABSTRACT

An understanding of the transport of scalars and pollutants in the atmosphere is essential in many engineering applications including the protection of the nation's health through enforcement of the Clean Air Act. Recent results from field experiments, laboratory experiments and numerical modeling efforts have advanced the theory of atmospheric transport. Some specific future research areas include transport in wake flows, dense-gas clouds and in the convective layer of the atmosphere.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group

18. DISTRIBUTION STATEMENT	19. SECURITY CLASS *(This Report)*	21. NO. OF PAGES
RELEASE TO PUBLIC	UNCLASSIFIED	6
	20. SECURITY CLASS *(This page)*	22. PRICE
	UNCLASSIFIED	

EPA Form 2220-1 (Rev. 4-77) PREVIOUS EDITION IS OBSOLETE

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WIND TRANSPORT OF SCALARS AND POLLUTANTS

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The release of radioactive materials in April of 1986 from the accident at the Chernobyl power plant in the U.S.S.R. made the world aware of the importance of the wind transport of pollutants [1]. Measurements of radiation at monitoring sites in Scandinavian countries were used in conjunction with meteorological data to help locate the radiation source. This long-range transport of a hazardous material affecting the health and welfare of hundreds of thousands of people is a dramatic example of how knowledge of the atmosphere and wind transport is important.

An understanding of the transport of scalars and pollutants in the atmosphere is essential in many engineering applications, from the protection of the nation's health through enforcement of the Clean Air Act to military applications of gas warfare and smoke camouflage. The role of the wind in atmospheric transport has been studied by theoreticians and experimentalists at an increasing rate through this century. Many full-scale field experiments have been conducted to provide measurements necessary to evaluate the various theories. Laboratory study of the atmosphere in wind tunnels and water tanks has become quite popular over the last thirty or so years. The rapidly increasing power of computers (in terms of memory size and speed) has made them modern tools for the study as well as prediction of atmospheric transport.

Studies of atmospheric transport can be categorized by a variety of factors: the material being transported (dust, passive gas, chemically reactive gases, dense gas, nuclear reactive matter, heat), the source type (point, area, moving), the condition of the atmosphere (neutral, stably stratified, convective), the transport distance of interest (short range of a few hundred meters to long range across countries or continents), the terrain or obstacle type (flat terrain, an isolated three-dimensional hill, a two-dimensional hill, complex terrain consisting of several hills, single buildings, building complexes, urban areas) and the method of study (theoretical, field, laboratory, numerical). Most combinations of these factors have been considered in various studies.

The Gaussian plume model [2] has been the workhorse for predicting pollutant concentrations. The model is based on empirical values of the standard deviations of the horizontal and vertical plume spread as functions of distance from the source and atmospheric stability. Originally derived from field data collected over flat terrain at fairly close proximity (1 km or so) to a point source, the model has been applied with many adjustments to a variety of terrain and source configurations. Virtual sources and "enhanced" or modified sigmas to account for terrain types or building influence have been used, most often based on very limited data.

Field studies have been performed to provide data bases for transport

model development, testing and evaluation. The Complex Terrain Model Development Project [3,4,5,6] being performed by Environmental Research and Technology, Inc. (ERT) under contract to the Environmental Protection Agency is a good example. The ultimate goal of this effort is to provide a regulatory computer model for prediction of concentrations from sources located near or within complex terrain situations. Three full-scale field experiments were conducted: one at Cinder Cone Butte, Idaho, an isolated, 100 m high, three-dimensional hill; one at Hogback Ridge, New Mexico, a long, 80 m high ridge; and one at the Tracy Power Plant near Reno, Nevada, located in a mountainous region. The data bases from these studies, along with data from the EPA Fluid Modeling Facility, have been used in the development work.

Fluid modeling of the atmosphere in wind tunnels and water tanks has become an important research and engineering method. Snyder [7] has prepared a comprehensive guideline for the application of fluid modeling to the study of atmospheric diffusion. The EPA has published specific guidelines [8] for the use of fluid modeling in the determination of "good engineering practice" stack heights to be used with EPA's stack height regulations (40 CFR 51). An example of the type of information that can be obtained from fluid modeling studies is the establishment of an integral formula for the prediction of the dividing-streamline height for stratified flow over a terrain obstacle. The formula, originally proposed by Sheppard [9], has been shown to be applicable to the flow over a wide variety of three-dimensional hills and fences in both stratified wind tunnels and towing tanks [10]. It was found to accurately predict the dividing boundary between flow passing over the top of the hill and that moving around the hill in nearly horizontal planes. The formula was applied quite successfully in tactical planning of the above mentioned field experiments by ERT and measurements showed it to be a valid indicator.

Numerical modeling of the wind transport of scalars and pollutants has developed nearly as rapidly as the required computer technology. Early computer models were mostly direct applications of a Gaussian plume formula for some particular situation or averaging time. As interest in diffusion from sources near complex terrain features and near buildings increased, the need for more sophisticated models has led to models which predict the mean flow field. The mean flow may be calculated from a potential flow model [11] or by numerical solution of the Navier-Stokes equations [12]. Then diffusion about the mean streamline through the source may be calculated, using a Gaussian plume or a Monte Carlo statistical formulation.

There are several future research projects that will benefit the theoreticians and modelers of the wind transport of pollutants. The wakes of buildings and hills are not yet sufficiently well understood to predict flow separation and the size of the resulting wakes. Techniques have become available to measure reverse flows (pulsed-wire anemometers) and fluctuating concentrations (fast-response flame-ionization detectors and computer-aided video analyses) to facilitate studies of diffusion in wake flows. Interest in dense-gas diffusion is increasing. The disaster at Lake Nios last August, with many deaths caused by a carbon dioxide cloud moving down a mountain valley, indicates a need for a better understanding of dense-gas transport. Fluid modeling in neutral and stable flows is fairly well established; however, there is much to be learned about diffusion in the convective layer

that can be modeled in the laboratory in convective tanks by continuing the work of Deardorff [13]. The combined effort of theoreticians, experimentalists (both field and laboratory) and modelers is required for the future development of the understanding and prediction of wind transport of scalars and pollution.

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